II. Physikalisches Institut

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HELMHOLTZ GEMEINSCHAFT

Cryogenic Stopping Cell and Multiple-Reflection Time-of-Flight Mass Spectrometer for Precision Experiments With Exotic Nuclei at GSI and FAIR

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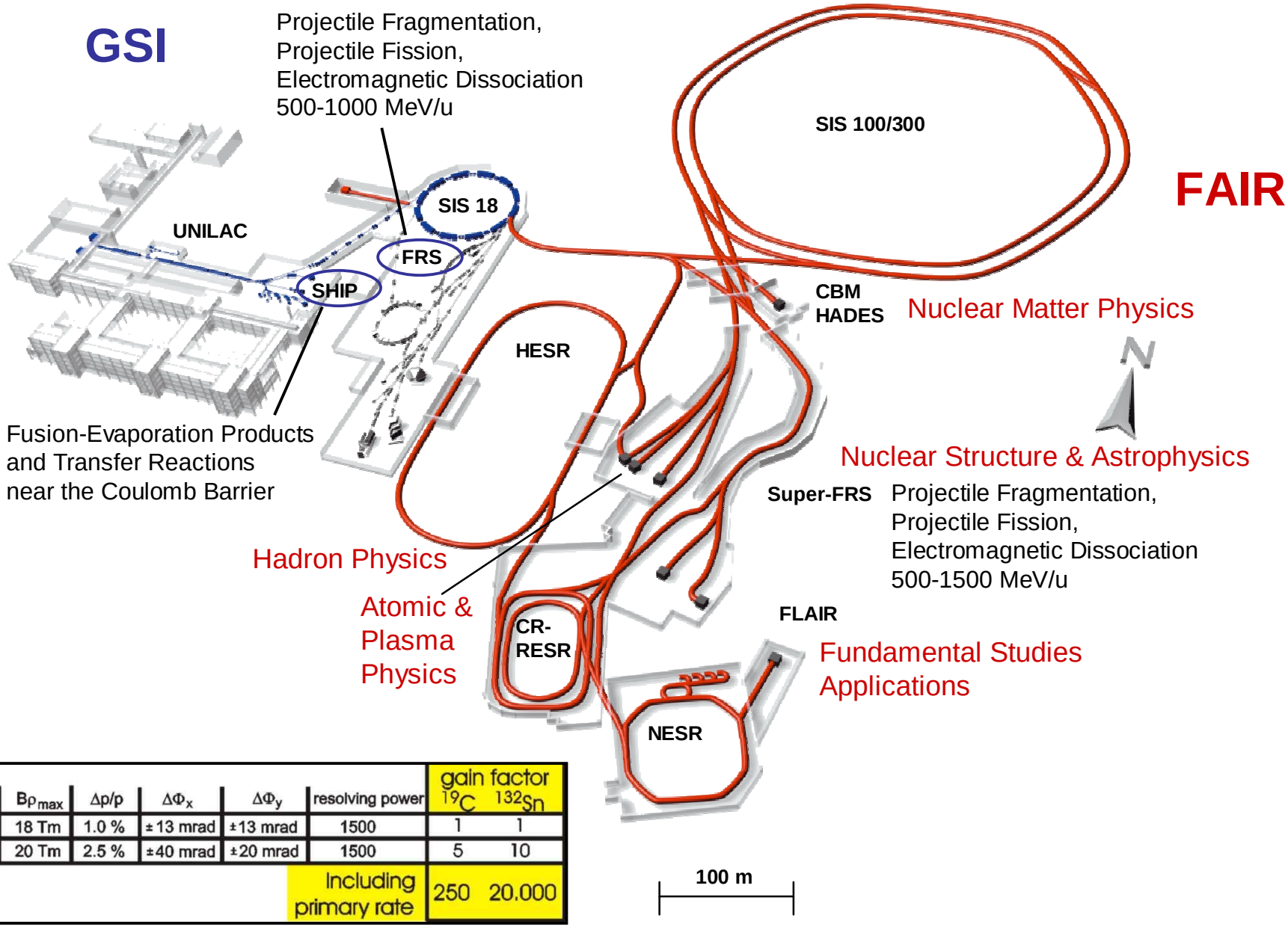
Overview

- Cryogenic Stopping Cell for the Super-FRS at FAIR
- Multiple-Reflection Time-of-Flight Mass Spectrometer
- On-line Commissioning at the FRS Ion Catcher at GSI
- Conclusions and Outlook

GSI and FAIR

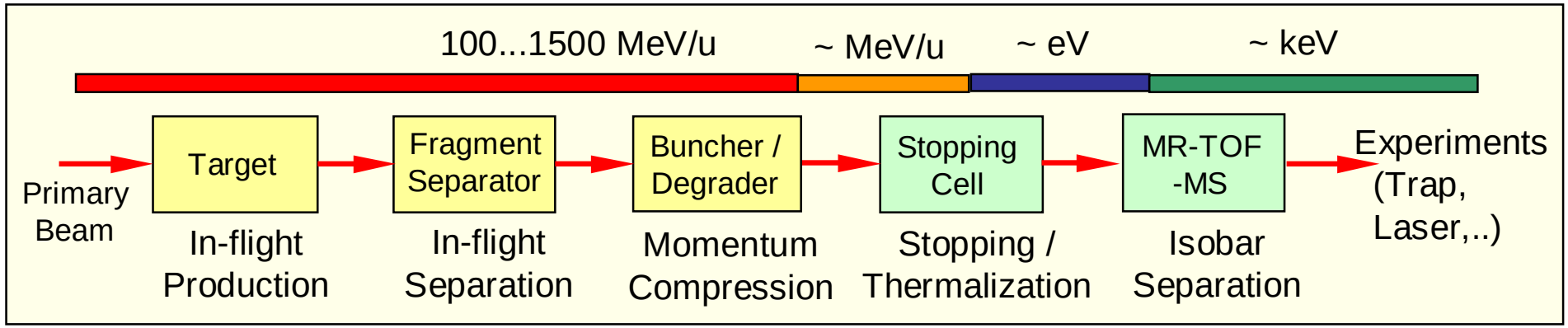


	$B\rho_{max}$	$\Delta p/p$	$\Delta\Phi_x$	$\Delta\Phi_y$	resolving power	gain factor ^{19}C	gain factor ^{132}Sn
FRS	18 Tm	1.0 %	±13 mrad	±13 mrad	1500	1	1
Super-FRS	20 Tm	2.5 %	±40 mrad	±20 mrad	1500	5	10
					Including primary rate	250	20,000

Motivation: Low Energy Branch of the Super-FRS

LEB: High-precision experiments with in-flight separated exotic nuclei almost at rest, (production by projectile fragmentation / fission)

- universal and fast production
- high selectivity
- cooled exotic nuclei

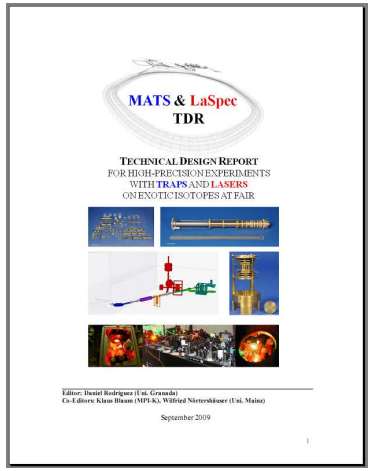


MATS (Precision Measurements of very short-lived nuclei using an Advanced Trapping System for highly charged ions)

- High accuracy mass measurements
- In-trap conversion electron and alpha spectroscopy
- Trap assisted spectroscopy

LaSpec (Laser Spectroscopy)

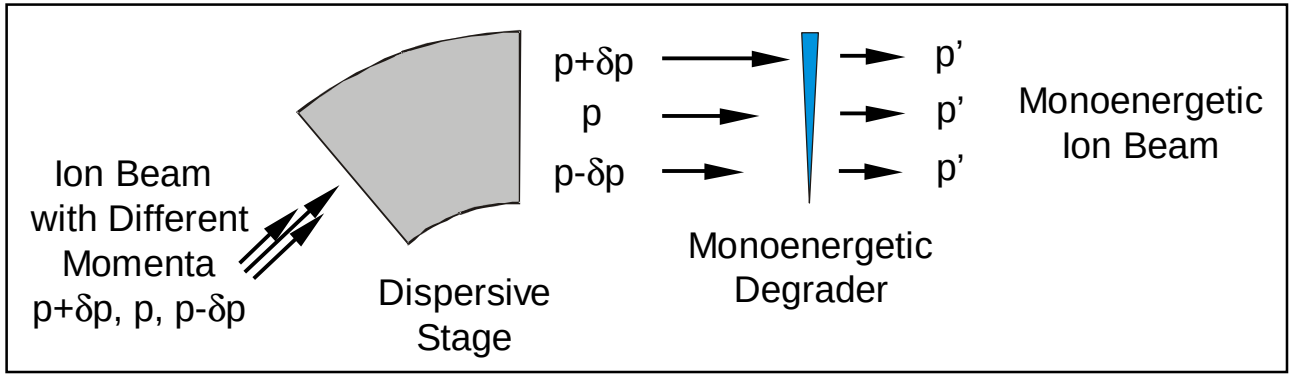
- Collinear laser spectroscopy of ions and atoms
- β-NMR
- Resonance ionization spectroscopy



Eur. Phys. J. Special Topics 183 (2010) 1

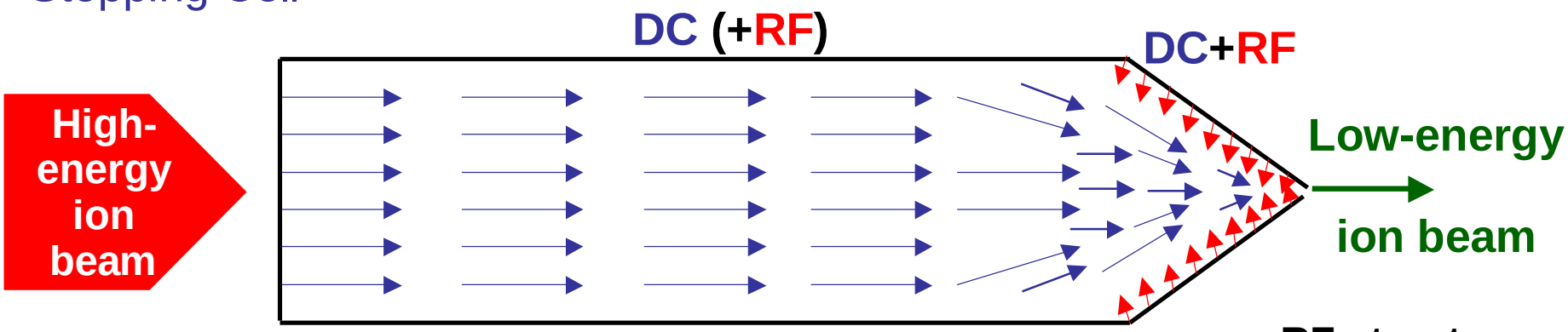
Stopping Cell Principles

Range Bunching



H. Geissel et al., NIM A 282 (1989) 247
H. Weick et al., NIM B 164 (2000) 168
C. Scheidenberger et al., NIM B 204 (2003) 119

Stopping Cell



M. Wada et al., NIM B 204 (2003) 570
G. Savard et al., NIM B 2004 (2003) 582

Stopping Cell Design

Cryogenic Operation

Operate He-filled stopping cell at cryogenic temperature (~70 K)

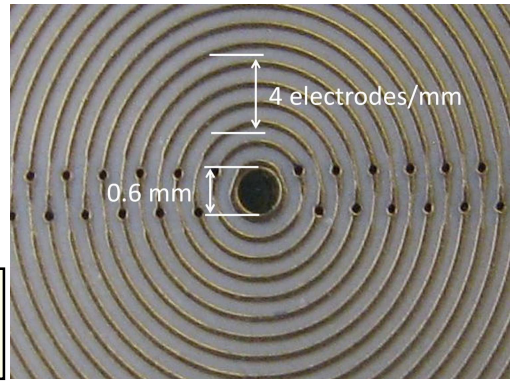
- Ultra-pure helium (freezing-out of contaminants)
  - Ideal for ion survival, 2+ charge state possible
  - No formation of molecules/adducts
- Reduced radial ion diffusion
- Reduced requirements for cleanliness → easier, more flexible construction
- Operational reliability

P. Dendooven et al., NIM A 558 (2006) 580
S. Purushothaman et al., NIM B 266 (2008) 4488

High-density Operation

Use RF structure with small spacing to achieve high RF repelling field (PCB-based RF carpet instead of RF funnel)

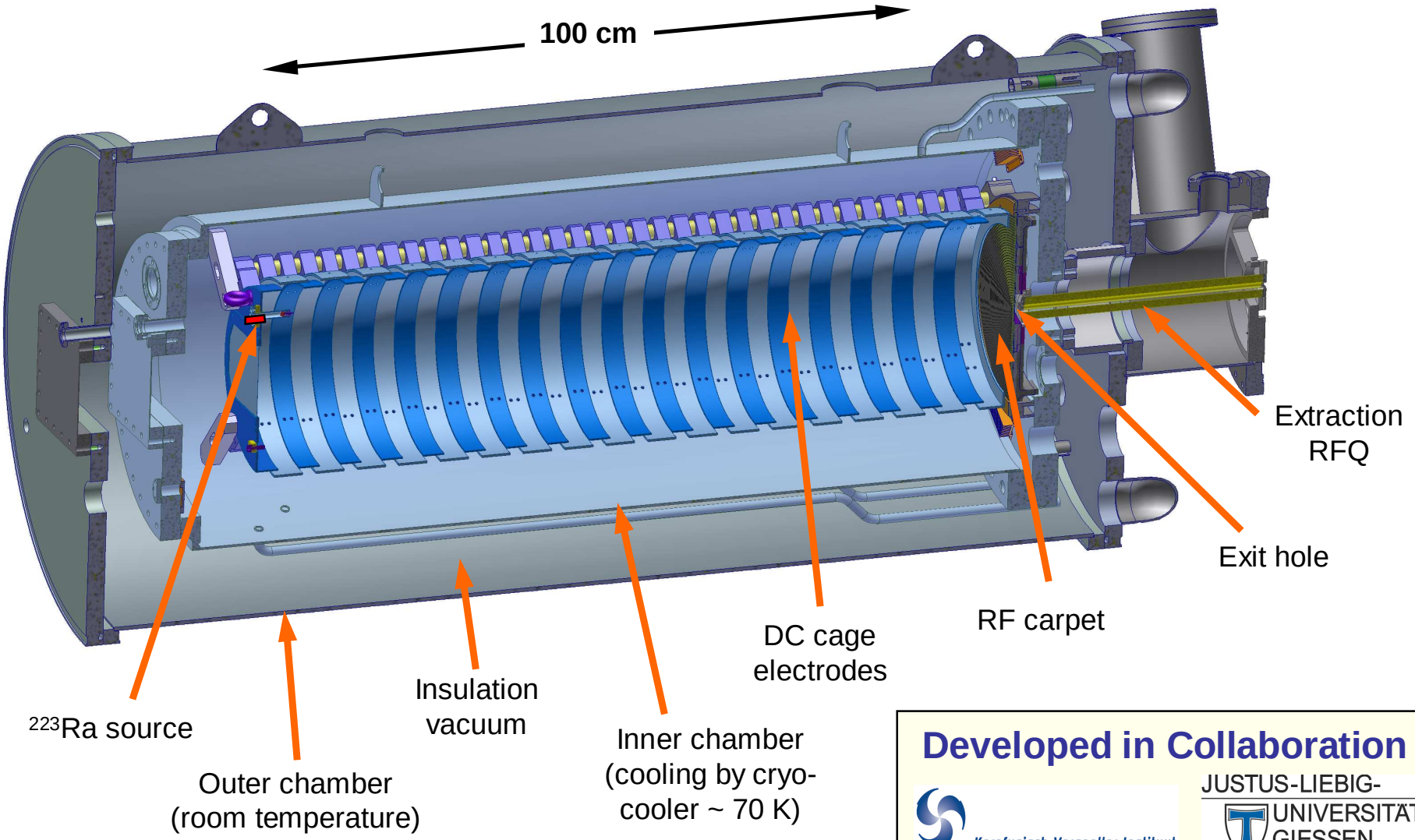
- High stopping gas densities
- Less complex construction than RF funnels



M. Wada et al., NIM B 204 (2003) 570
M. Ranjan et al., Europhys. Lett. 96 (2011) 52001

Diameter:	250 mm
Electrode spacing:	0.25 mm

Stopping Cell Design



Developed in Collaboration

Kernfysisch Versneller Instituut

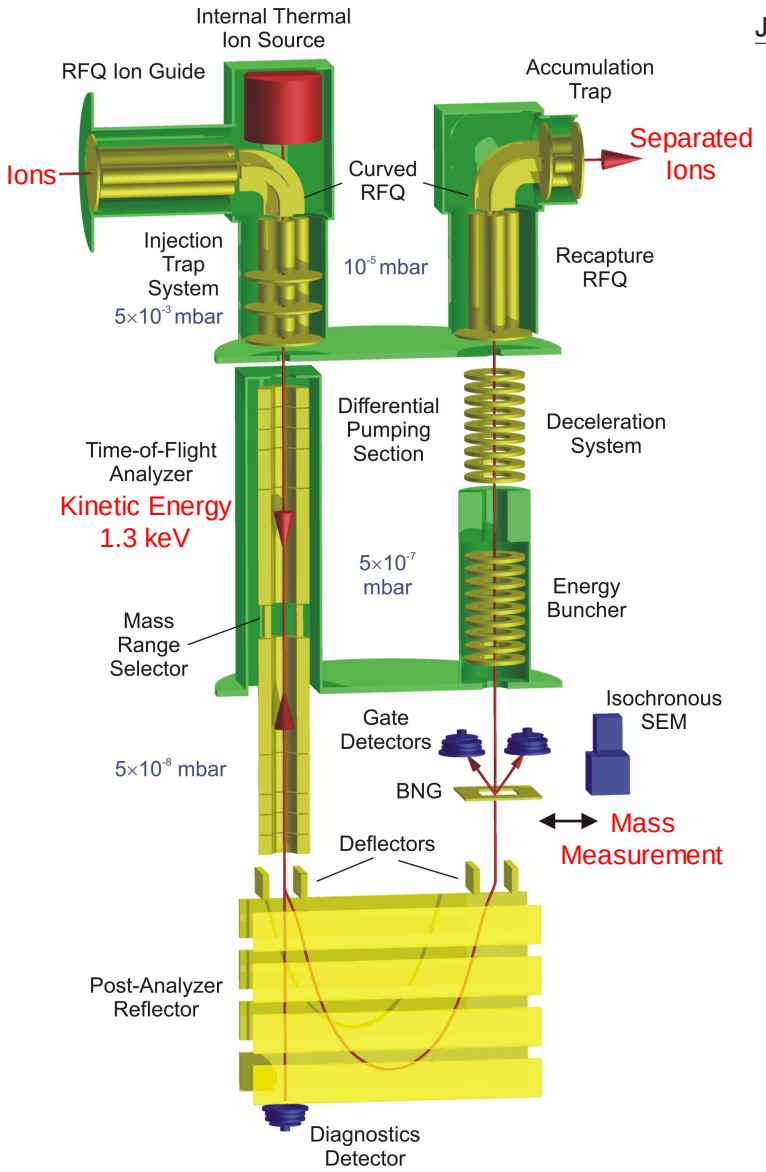
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

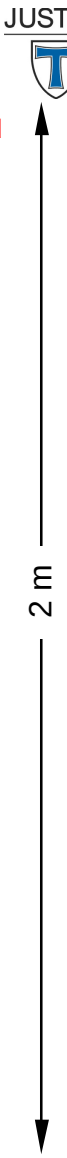
university of groningen

GSI

M. Ranjan et al., Europhys. Lett. 96 (2011) 52001
M. P. Reiter, Master Thesis, Justus-Liebig-Universität Gießen (2011)

Multiple-Reflection Time-of-Flight Mass Spectrometer





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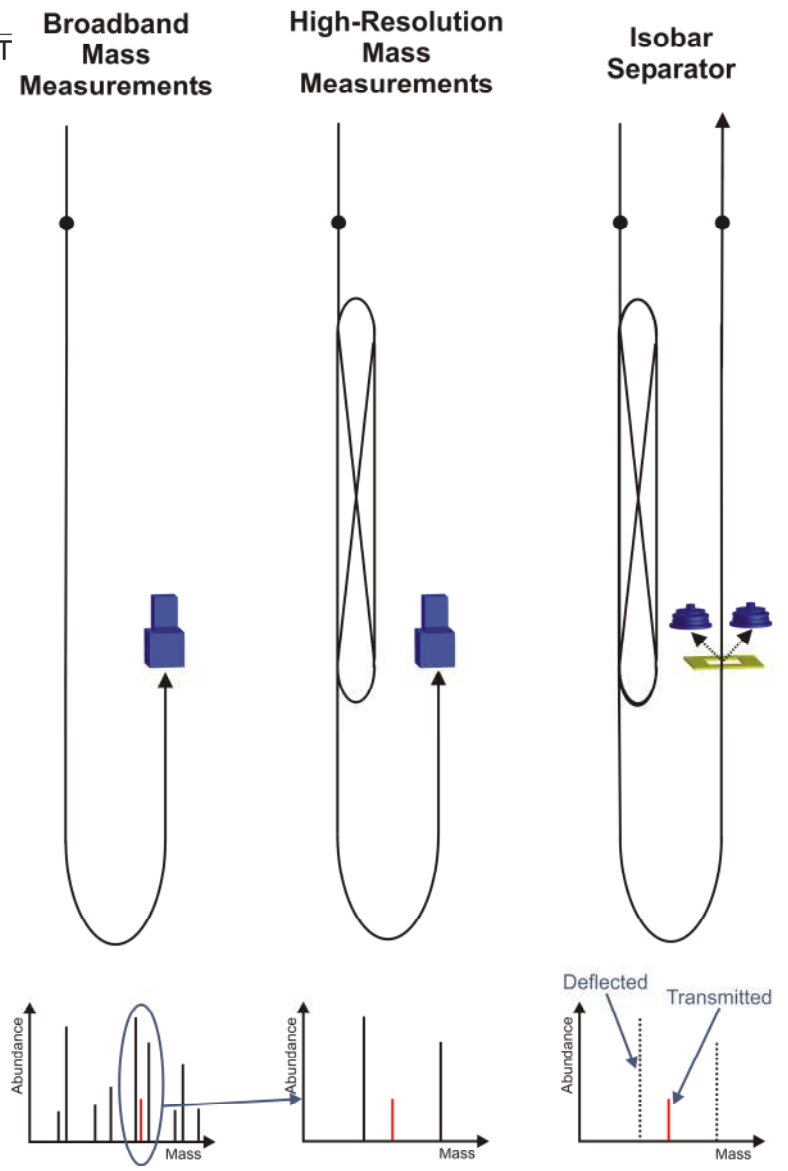


W.R. Plaß et al., NIM B 266 (2008) 4560
W.R. Plaß et al., Int. J. Mass Spectrom. 394 (2013) 134

Full Mass Range, $m/\Delta m \sim 10^3$-10^4

$m/\Delta m \sim 10^5$-10^6, Mass Accuracy ~ 10^{-6}-10^{-7}

$m/\Delta m > 10^5$

Performance Characteristics of the MR-TOF-MS

Universal mass spectrometer and mass separator
(works for all elements, stable and unstable ions)

Mass Resolving Power

600,000

Repetition Rate

up to 400 Hz

Mass Measurement Accuracy

~10^{-7}

Transmission efficiency

up to 70%

Measurement Duration

~10 ms

Ion Capacity

> 10^6 ions / s

Sensitivity

~10 ions

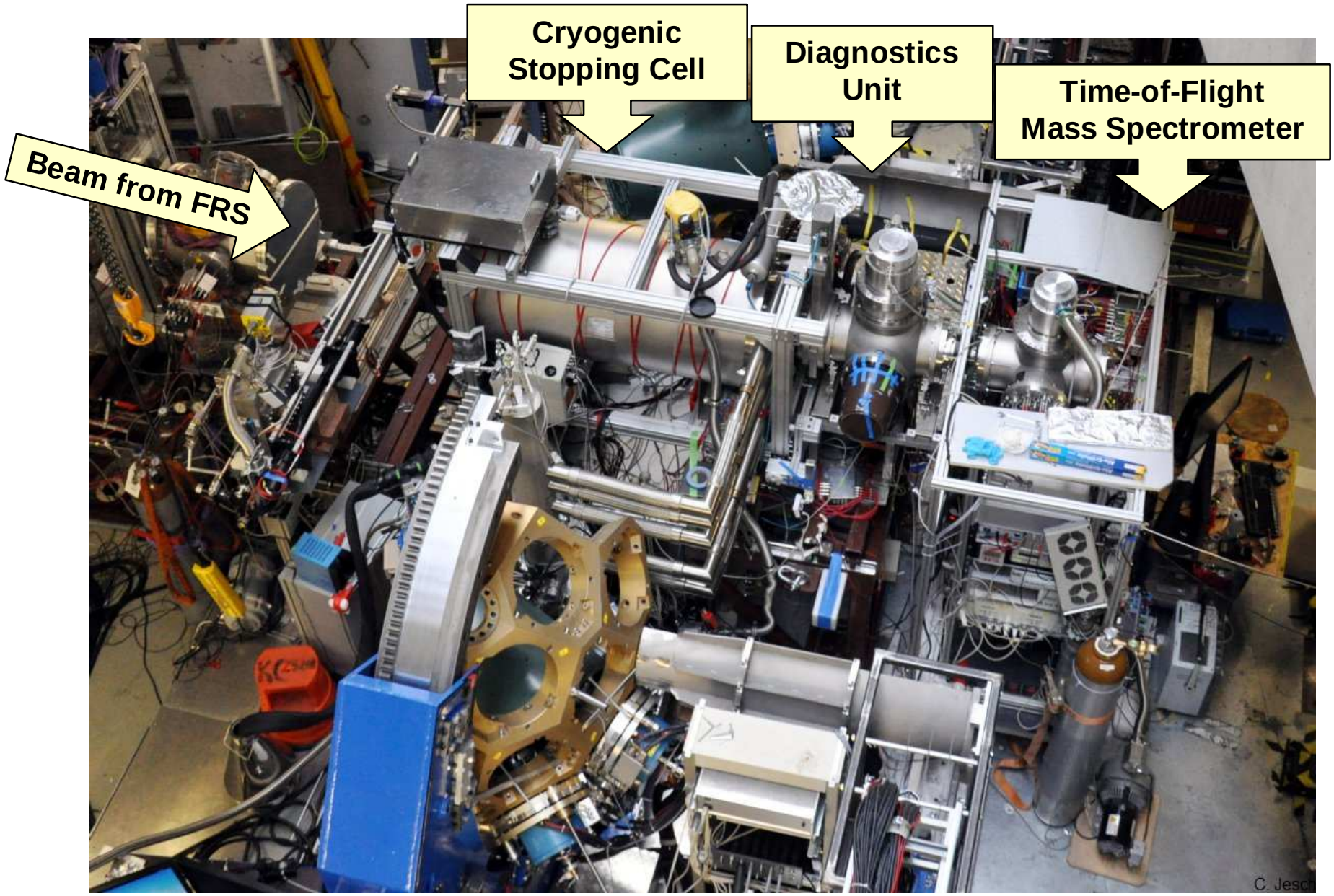
Dynamic Range

> 10^4

World-wide unique combination of performance characteristics!

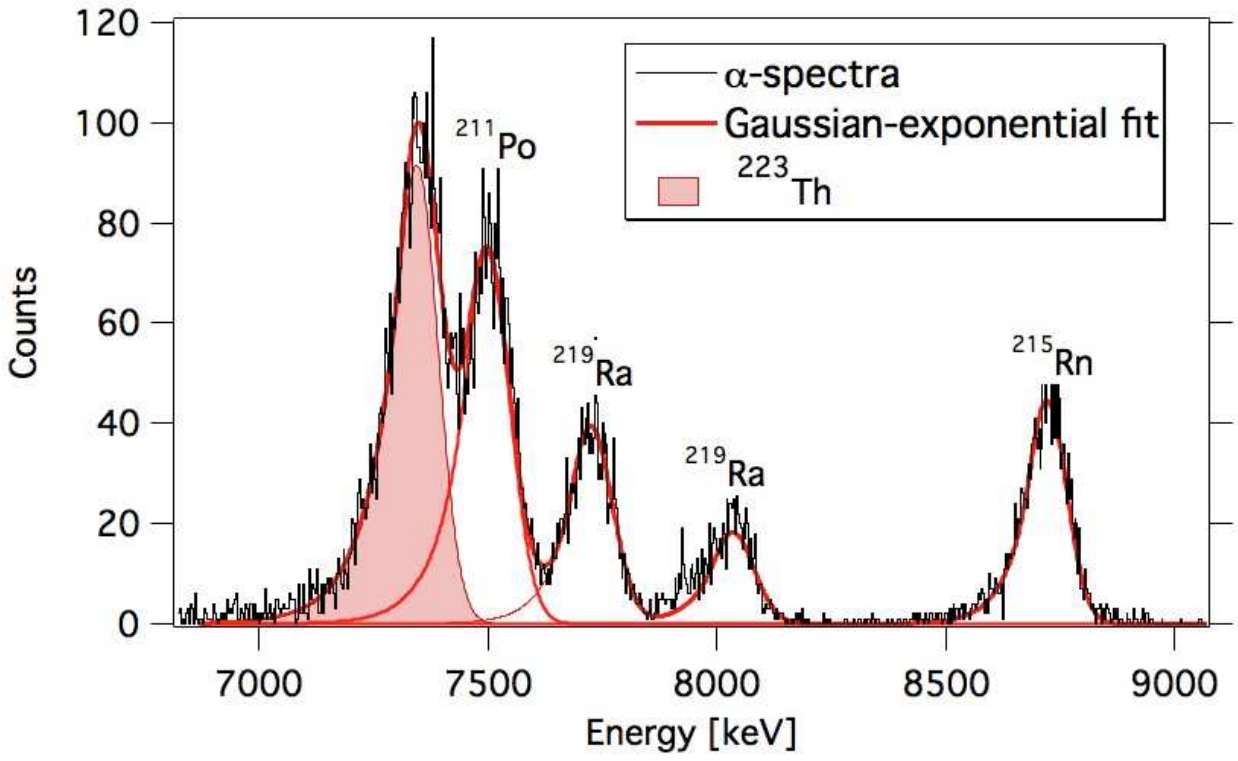
Further performance improvements are underway.

FRS Ion Catcher Experiments in 2011 / 2012

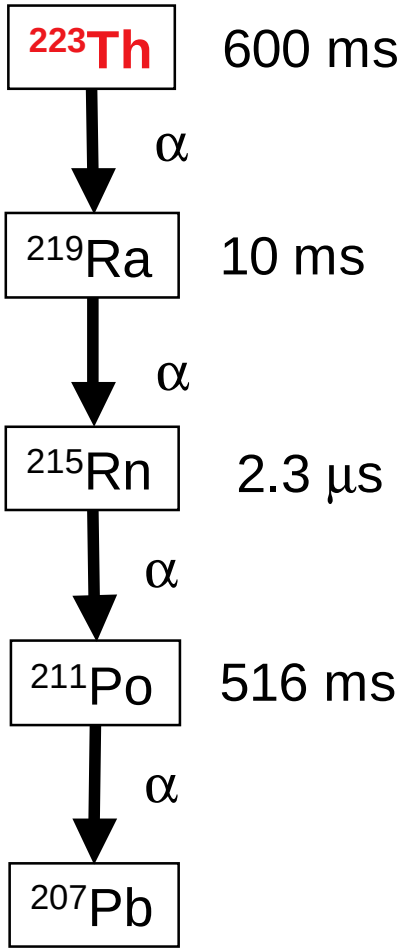


Stopping Cell Performance

Si detector spectrum of extracted projectile fragments



extracted as 2+

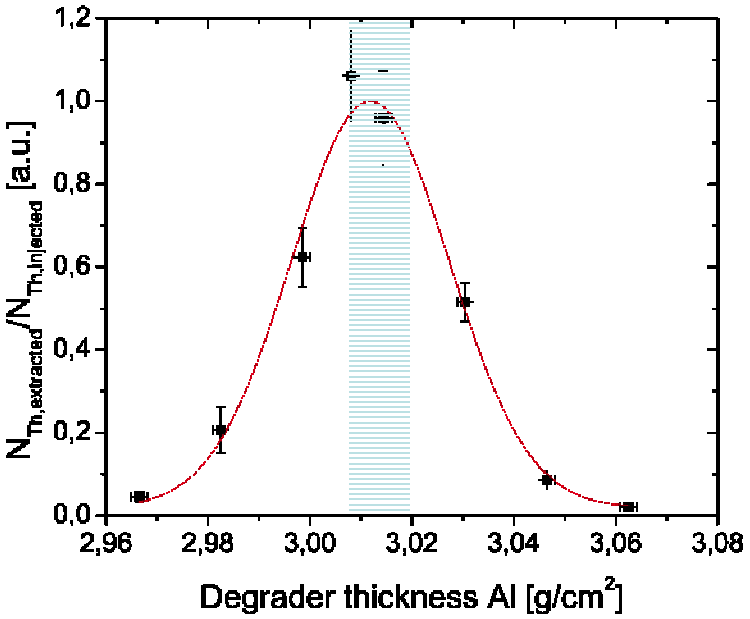


First on-line operation of a cryogenic stopping cell for exotic nuclei

S. Purushothaman et al., EPL (in print)

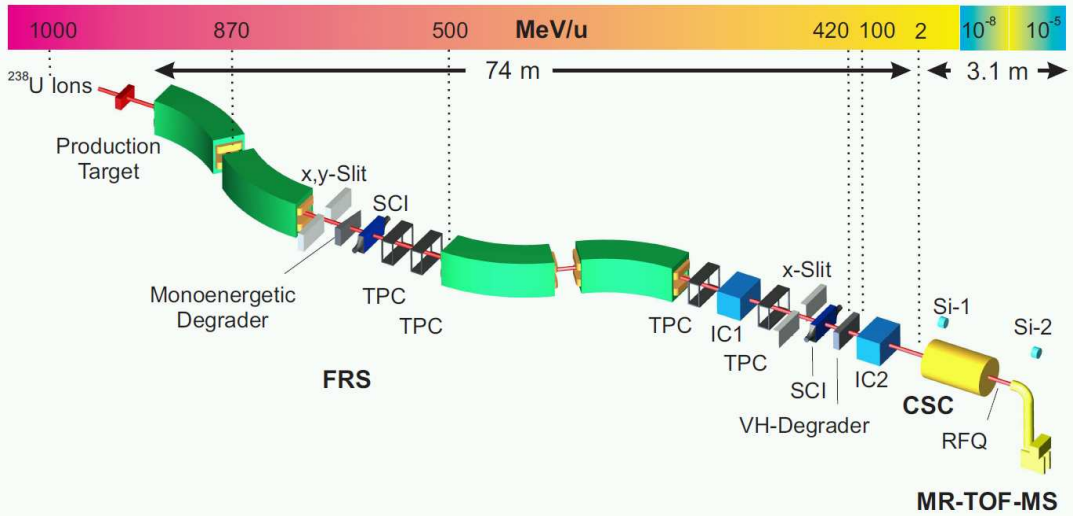
Stopping and Extraction Efficiencies

Range distribution of ^{223}Th



- Range distribution:
  - σ = 13.5 mg/cm^2 (Al)
  - σ = 7 mg/cm^2 (He)
- Stopping cell: 100 mbar, 100 K
  - → Areal density: 5 mg/cm^2 (He)
  - → corresponds to ~ 300 mbar at room temperature

Almost 2 times higher gas density compared to other stopping cells using an RF structure



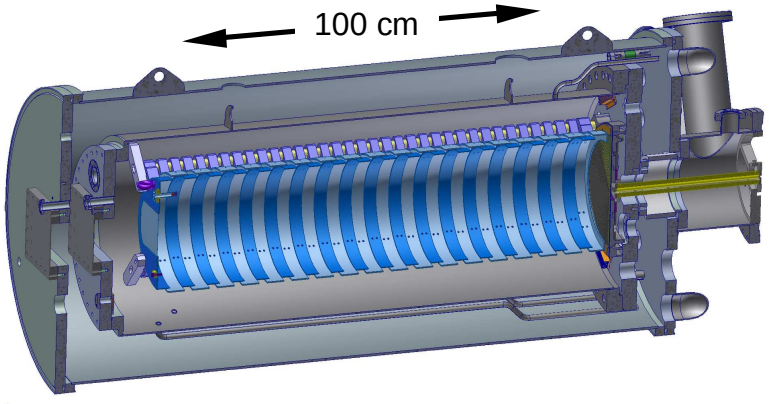
S. Purushothaman et al., EPL (in print)

Stopping and Extraction Efficiencies

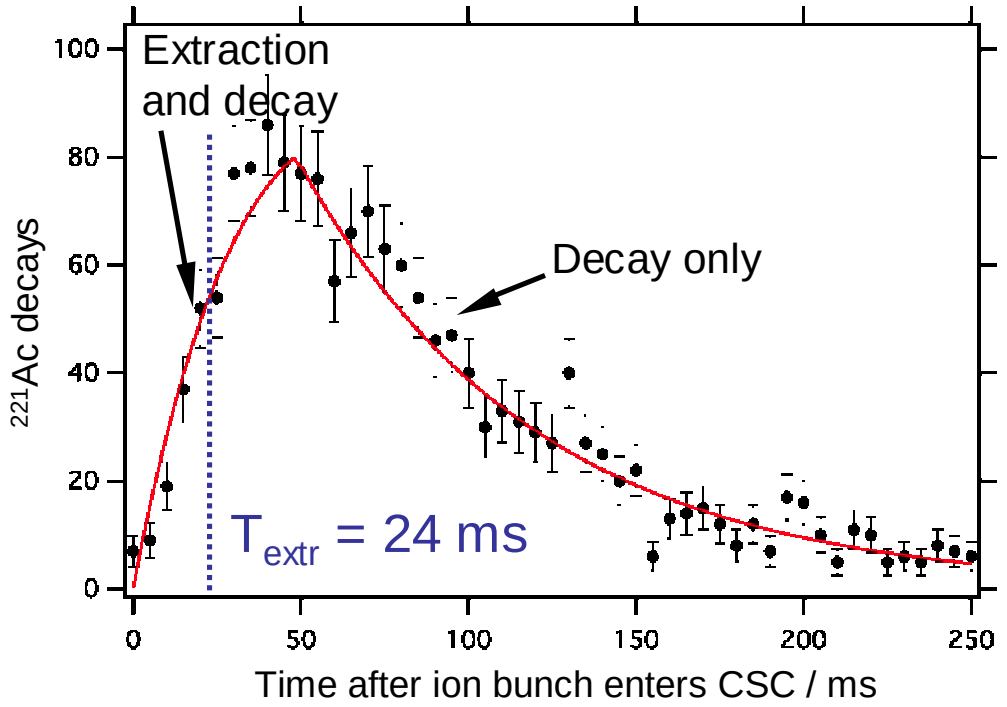
	Experiment 2011	Experiment 2012
Pressure / mbar	98	47
Temperature / K	100	78
Areal Density / (mg/cm² He)	4.9	3.1
^{223}Th		
Range Distribution (σ) / (mg/cm² He)	6.7	6.85
Stopping Efficiency / %	27.0 ± 2.4	15.9 ± 1.8
Survival and extraction efficiency / %	43 ± 7	62 ± 12
Total Efficiency / %	11.6 ± 1.6	9.9 ± 1.5
^{221}Ac		
Stopping Efficiency (calc.) / %		15.7 ± 1.8
Survival and extraction efficiency / %		49 ± 11
Total Efficiency / %		7.7 ± 1.6
^{219}Rn		
Stopping Efficiency (calc.) / %	25 ± 2.4	
Survival and extraction efficiency / %	58 ± 9	
Total Efficiency / %	14.5 ± 2.0	

Extraction Time

Extraction time measurement using short ^{221}Ac ion bunches ($T_{1/2}$ = 52 ms)



Pressure = 49 mbar, Temperature = 75 K
DC field = 23.2 V/cm, 6 ms spill length



Comparison of results

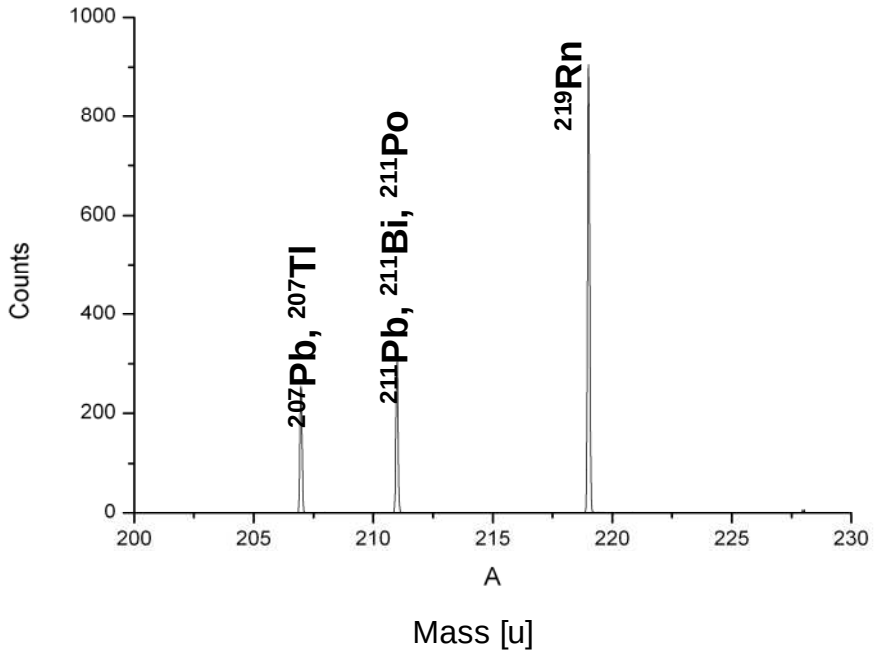
	Experiment	Theory (K_0=15 cm^2/Vs)
Online (49 mbar, 75 K, 23 V/cm)	24 ms	27 ms
Offline (50 mbar, 102 K, 19 V/cm)	25 ms	24 ms

W.R. Plaß et al., NIM B 317 (2013) 457; S. Purushothaman et al., EPL (in print)

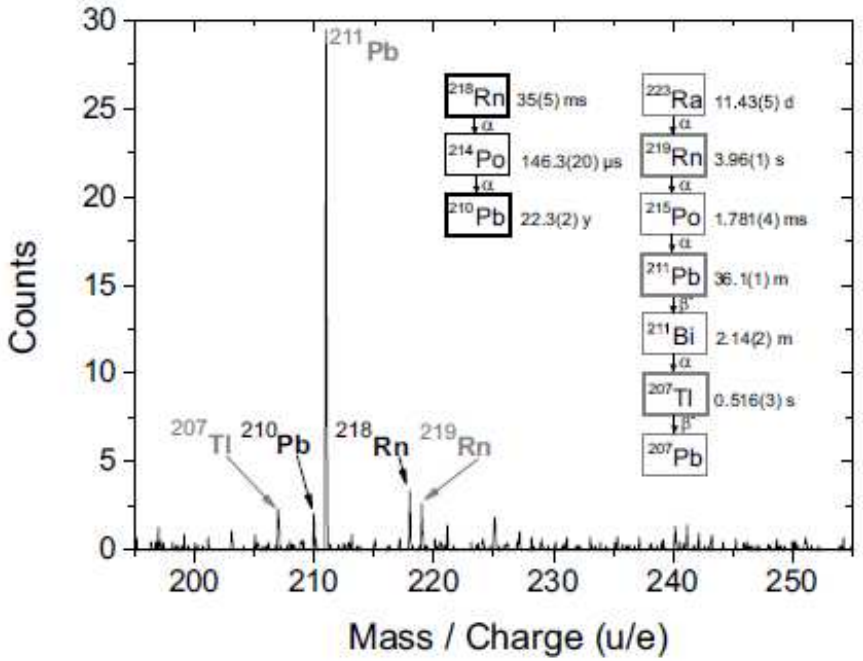
Cleanliness of the Stopping Cell

Broadband mass spectra taken with the MR-TOF-MS

Offline with ^{223}Ra Source



With Beam

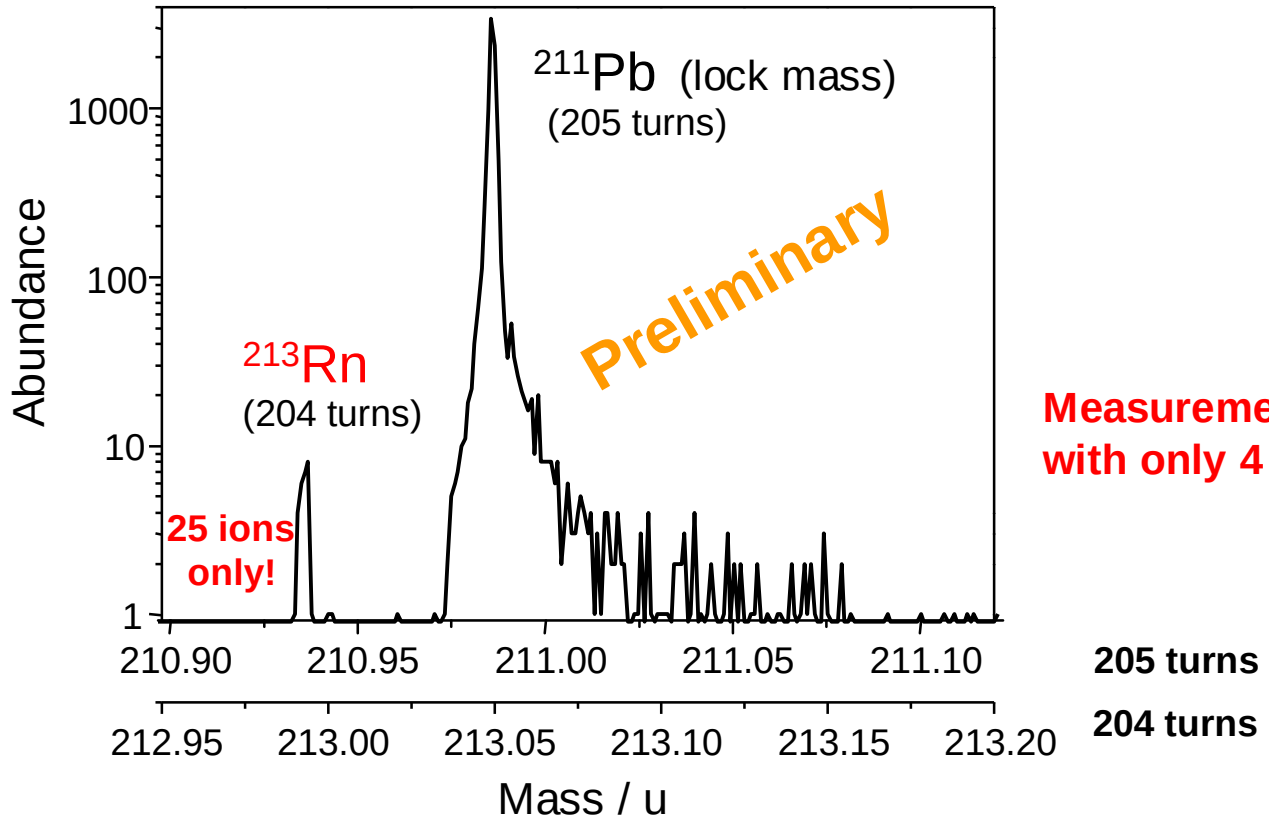


- Molecular contaminants / adduct formation are not a problem for the cryogenic stopping cell
- Broadband mass spectrometry is a necessity for quick and reliable operation of a stopping cell

J. Ebert; S. Purushothaman et al., EPL (in print)

MR-TOF-MS Mass Measurements

First direct mass measurement of ^{213}Rn ($T_{1/2}$ = 19.5 ms)



Measurement performed with only 4 ^{213}Rn ions/hour

First direct mass measurement of projectile fragments with an MR-TOF-MS:

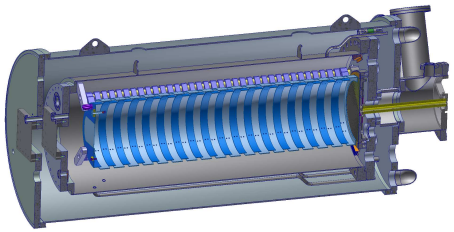
- **^{211}Po and ^{211}Rn, ^{213}Rn**

T. Dickel et al.

Conclusions

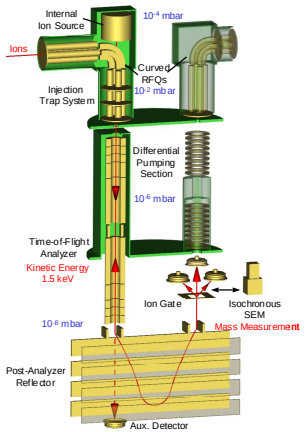
Stopping cell for the Super-FRS and the FRS Ion Catcher

- Cryogenic, high density operation, suitable for exotic nuclei produced at relativistic energies
- Commissioned off-line and on-line
- Preliminary performance values (^{238}U fragments):
  Stopping efficiency up to ~ 25%
  Survival and extraction efficiency ~ 50%
  Extraction time ~ 25 ms



High-performance multiple-reflection time-of-flight mass spectrometer

- Mass resolving power up to 600.000 at 50% transmission
  Mass measurement accuracy down to 10^{-7}
  Cycle time ~ 10 ms
  Single ion sensitivity
- First direct mass measurements of heavy projectile fragments
- High-resolution mass separator
- Diagnostics tool: identification and quantification



Outlook

Cryogenic stopping cell

- Systematic study of the cryogenic stopping cell
  (e.g. intensity limitations, temperature effects)
- Test with fission fragments
- Increase stopping efficiency even further (higher densities)
- Develop final version of the stopping cell for the LEB

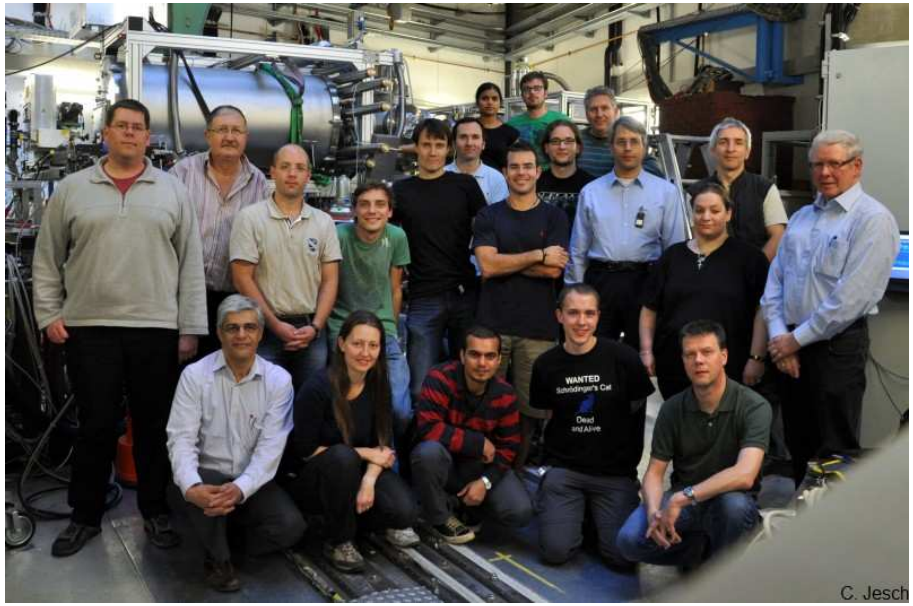
MR-TOF-MS

- Further performance improvements
  (higher voltages, highly stable HV, cryogenic injection trap,
  ultra-high-performance analyzer, etc.)
  $\rightarrow$ Resolving power > 10^6 $\rightarrow$ Isomer separator!
- Systematic study of mass measurement accuracy,
  laser ablation ion source for mass calibration
- Perform mass measurements at the FRS Ion Catcher,
  SHIP, TRIUMF, JYFL, ...;
- Applications in analytical mass spectrometry

Acknowledgements

FRS Ion Catcher / S411 Collaboration

F. Amjad[2], S. Ayet[2], T. Dickel[1,2], P. Dendooven[3], M. Diwisch[1], J. Ebert[1], A. Estrade[2], F. Farinon[2], H. Geissel[1,2], F. Greiner[1], E. Haettner[1], C. Jesch[1], N. Kalantar-Nayestanaki[3], R. Knöbel[2], J. Kurcewicz[2], J. Lang[1], I. Moore[4], I. Mukha [2], C. Nociforo[2], M. Petrick[1], M. Pfuetzner[2], W.R. Plaß[1,2], S. Pietri[2], A. Prochazka[2], S. Purushothaman[2], M. Ranjan[3], M.P. Reiter[1], A.-K. Rink[1], S. Rinta-Antila[4], C. Scheidenberger[2], M. Takechi[2], Y.K. Tanaka[2], H. Weick[2], J.S. Winfield[2], M.I. Yavor[6]



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[4] University of Jyväskylä, Jyväskylä, Finland
[5] Faculty of Physics, University of Warsaw, Warszawa, Poland
[6] Institute for Analytical Instrumentation, RAS, St. Petersburg, Russia

Funding: **Univ. Groningen** and **GSI**,
BMBF (06GI185I, 06GI9114I, 05P12RGFN8),
State of Hesse (HMWK) (LOEWE Center HICforFAIR),
JLU Giessen and **GSI** (JLU-GSI strategic Helmholtz partnership agreement)